EDGES MEMO #035

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September 14, 2007

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To: EDGES Group
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Subject: Some notes on various switching schemes

Looking for a spectral line which occupies a substantial bandwidth is very challenging. As discussed in memo #27 wideband direct sampling has switching limitations. The initial EDGES spectrometer used only 3 position switching (antenna, load and load + calibration) which failed to adequately reduce the systematics. Since a broadband mixer has a very smooth conversion loss various with frequency types of switching like the frequency commutation or cycling are useful for reducing systematics as discussed in memo #34. Frequency scanning systems like the traditional spectrum analyzer suffer from poor "spectral efficiency" since only a given part of the spectrum is observed for a small fraction of the time.

1] 3- position switching

In order to reduce the SNR loss the calibration noise needs to increase the total power by a substantial fraction. In practice the 3-position switching increases the noise by 6½ or 6 times the observing time is required to reach the same random noise level. This is a high cost for reduced systematics.

2] Frequency switching

Conventional frequency switching for which the signal only appears in "signal" and not in the "comparison" increases the noise by 2 or 4 times so that much more observing time is required. Frequency switching for which the signal is present in both the "signal" and "reference" portions of switching cycle is more efficient. A simple frequency switching scheme uses 3 frequency bands arranged with the "signal" band surrounded by adjacent equally weighted "reference" bands on either side. With this scheme any systematics which repeat with each frequency cycle cancel. In addition, "baseline" variations in the spectrum are reduced by 2 orders in the polynomial fit. For example a spectrum which contains a constant, slope and curvature is reduced to just a constant.

A more efficient scheme for a narrow band spectral line, is the "half-bandwidth" switching scheme which places the spectral line in both the "signal" and "comparison" band. In this case, the spectral line in emission can be made to appear as a positive signal in the lower half of the band and as a negative signal in the upper half of the band. Then, if in post processing, the upper half of the band is subtracted from the lower half the SNR for the line is only reduced by $2^{½}$ over a total power spectrum. This scheme reduces systematics by 2 orders in the polynomial fit and reaches the same sensitivity as an unswitched system is only twice the observing time.

3] Frequency commutation

In this system the “signal” is always present so there is no subtraction of a “comparison.” However, there is a loss of SNR if the instantaneously processed bandwidth is a fraction of the total bandwidth.

4] Sensitivity for EDGES

If there is a 40 mK signal at about 140 MHz then this signal is about 10^{-4} of the sky noise. The noise in 1 hour for 1 MHz resolution is 2×10^{-5}. With 3-position switching, which is most likely required, this time to reach the same level is 6 hours. If, in addition, only 4 MHz out of 100 MHz are processed this time increases to 150 hours 4 MHz is probably the absolute minimum acceptable bandwidth.

5] VSRT tests on long integrations

There are 2 atmospheric spectral lines available to VSRT:

The 11.0724545 GHz line of ozone and the 13.4414173 GHz line of OH. If these ozone and OH transitions are in thermal equilibrium with kinetic temperature the expected peak signal to system temperature ratio is about 2×10^{-4} at 7° elevation for both lines for a 70K system temperature. A separate memo will describe the details of the setup for VSRT spectral line observations. The EDGES “mini” use spectrometer has analyses a 1 MHz bandwidth with only 20% spectral efficiency. It takes many days of observing to reach noise levels of 10 ppm needed for a reliable detection.

Switching scheme	Noise increase	Systematic reduction order of polynomial
3-position (ant, load, cal)	$6^{1/2}$	
frequency commutation	$R^{1/2}$	
frequency switching	$2R^{1/2}$	2
half-bandwidth switching.	$2^{1/2}(2R)^{1/2}$	2

Table 1. Performance of various switching schemes.

R = ratio of spectrum width covered to instantaneous bandwidth.